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Earthquake swarms reveal submarine magma unrest induced by distant mega-earthquakes: Andaman Sea region

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ABSTRACT

Little is known about earthquake-triggered magma intrusions or eruptions of submarine volcanoes. The analysis of teleseismic earthquake occurrence performed in this study offers a tool to address such enigmatic and inaccessible processes. In the past ten years, the Andaman Sea region repeatedly became a site of shallow earthquake swarms that followed distant mega-earthquakes by days to weeks. The M_W 9.1 December 26, 2004 Sumatra–Andaman earthquake was followed by two earthquake swarms about 600 km northward in the Andaman Sea region, delayed by 30 and 35 days, respectively. Earthquakes of one of these seismic episodes, the extensive January 2005 earthquake swarm, migrated laterally at a rate of about 0.25 km per hour during the swarm evolution. The strong Indian Ocean M_W 8.6 and 8.2 April 11, 2012 earthquake doublet west of Northern Sumatra was followed by an earthquake swarm approximately 800 km northward in the Andaman Sea region, delayed by 13 days. All the three swarms that followed the 2004 and 2012 mega-earthquakes occurred beneath distinct seamounts and seafloor ridges. Based on the observations of migration of earthquakes during the swarm and swarm occurrence beneath distinct highs at the seafloor, we conclude that these earthquake swarms probably resulted as a consequence of magma unrest induced by static and/or dynamic stress changes following the distant mega-earthquakes. Repeated occurrence of such a phenomenon suggests that the arc magma reservoirs beneath the Andaman Sea have recently reached some form of criticality and are vulnerable to even small stress changes. The Andaman seafloor could thus become a site of submarine volcanic eruptions in near future and deserves close attention of Earth scientists.

1. Introduction

Triggering of volcanic eruptions and of volcanic unrest by distant earthquakes has been a subject of numerous studies and reviews (e.g. Hill et al., 2002; Manga and Brodsky, 2006). The triggering process may involve either static or dynamic stress changes (Hill et al., 2002). Static stress change is induced by displacement of rock masses during an earthquake. It decays rapidly in space and seismo-volcanic interactions by such a mechanism are limited to distances of few fault lengths/source dimensions. Dynamic stress changes are carried by passing seismic waves and can act as a triggering mechanism at global distances (e.g. Husen et al., 2004; Hill and Prejean, 2007). Mechanisms exciting a magma plumbing system by stress changes from distant earthquakes are summarized and discussed e.g. by Manga and Brodsky (2006).

Excitation of a magma plumbing system by stress changes resulting from distant earthquakes may be indicated by earthquake swarms that, in general, are thought to be a consequence of magma migration beneath volcanic edifices (e.g. Roman and Cashman, 2006). Repeated occurrence of earthquake swarms beneath a volcanic arc several days to weeks after strong distant earthquakes could indicate that respective volumes of arc magma have reached some form of criticality and could be precursory to impendent eruptions from sources on the seafloor in near future.

2. Tectonic setting and recent dynamics

The Andaman Sea region and the neighboring part of the Indian Ocean south of it are situated in the area of convergence of the Australian Plate and the Southeast Asian Plate (Fig. 1). Recent dynamics of the region is dominated by two processes: oblique subduction of the Australian Plate along the N–S to NNW–SSE oriented Andaman–Nicobar–Sumatra trench, and normal convergence of India and Eurasia. Surface manifestations of these processes include: (i) calc-alkaline volcanoes of northern Sumatra, (ii) Barren and Narcondam subareal volcanoes in the north, (iii) numerous seamounts and ridges at the seafloor in between, (iv)

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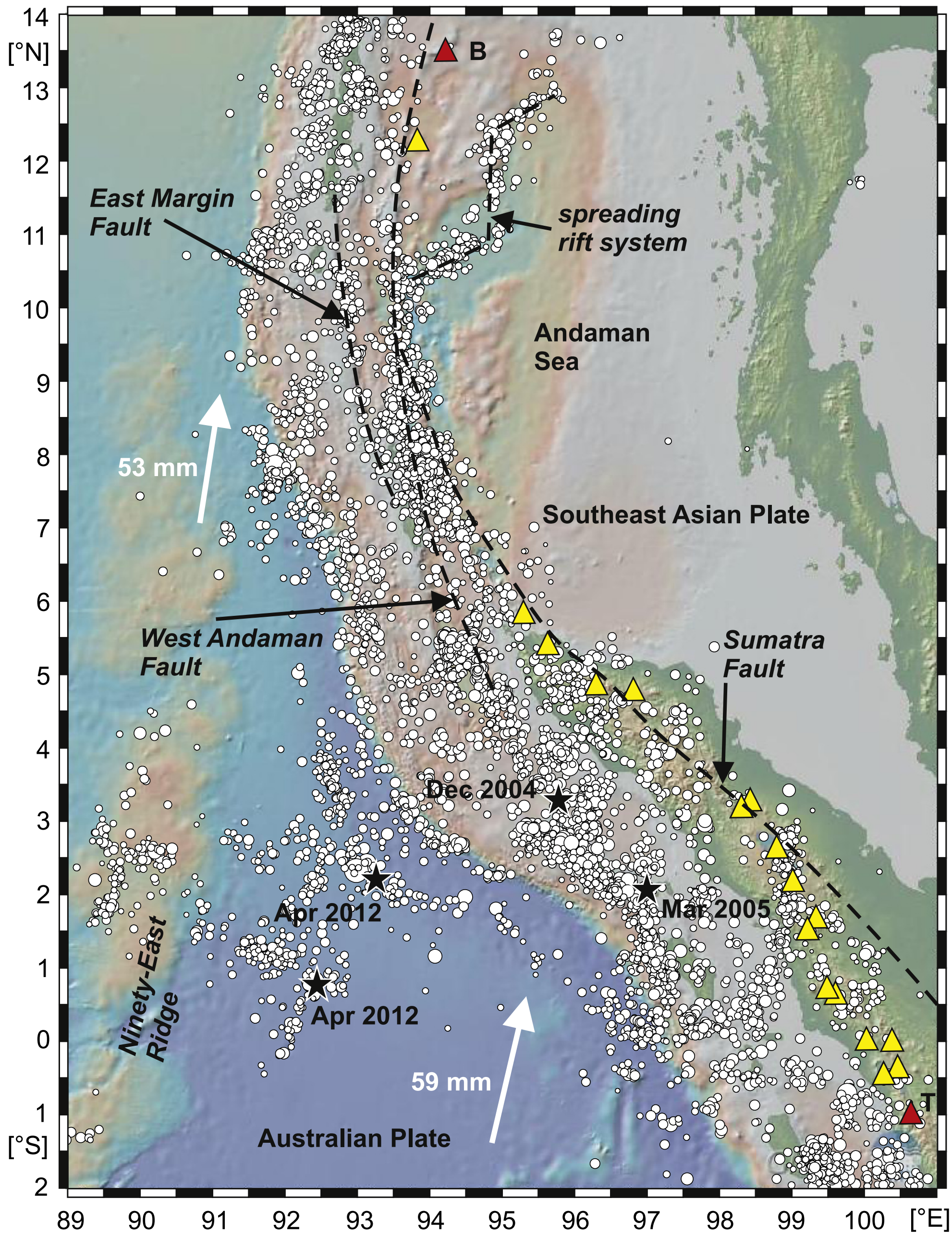

Fig. 1. Epicentral map 1960 – March 2013 (white circles) of the Andaman Sea region, northern Sumatra, and the part of the Indian Ocean west of it. Size of circles is proportional to body wave magnitude m_b. Black stars denote epicenters of great earthquakes of the last decade. Yellow triangles denote active subareal volcanoes, red triangles volcanoes that erupted in 2005: B – Barren Island, T – Telong. White arrows denote direction of northward movement of the Australian Plate. Image created using GeoMapApp (www.geomapapp.org, Ryan et al., 2009). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

an extensional spreading rift system of the Andaman Sea, (v) a system of NNW–SSE oriented right-lateral Sumatra, West Andaman and East Margin Faults, and (vi) the Ninety-East Ridge.

Seismic activity of the investigated area reflects the trends of recent dynamics being concentrated along/beneath some of these structural elements (Fig. 1). The detailed analysis of regional earthquake occurrence (Špičák and Vaněk, 2013) indicates frequent occurrence of earthquake swarms along a narrow trench-parallel belt beneath the submarine portion of the Sunda volcanic arc. The swarms are interpreted as a consequence of episodes of magma migration in the plumbing system of the volcanic arc.

Regional seismicity pattern was substantially influenced by the M_W 9.1 December 26, 2004 Sumatra–Andaman earthquake (Figs. 1 and 2a), the following M_W 8.6 March 28, 2005 Northern Sumatra earthquake (Fig. 1) and the M_W 8.6 and 8.2 April 11, 2012 Indian Ocean earthquake doublet (Figs. 1 and 2b).

The most notable feature of the aftershock sequence following the M_W 9.1 December 2004 event was the extensive January 2005 earthquake swarm. The swarm that started 30 days after the mainshock and lasted 10 days stands among the most energetic swarms ever recorded. It attracted attention of Indian geologists and geophysicists (Raju et al., 2012; Kundu et al., 2012) who – based on seismological data analysis (*b*-value, focal mechanisms) and site survey (multibeam bathymetry, seafloor imaging, rock sampling) – pointed to the decisive role of magmatic fluids activated by the M_w 9.1 earthquake in the January 2005 earthquake swarm generation.